Air Distribution and Microenvironment Evaluation of a Desktop Task Conditioning System[1]

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Abstract: Task conditioning aims to provide each occupant with personalized clean air direct to the breathing zone. The microenvironment of a typical office workplace, consisting of two desktop task conditioning systems (a Horizontal Desk Grill (HDG) and Vertical Desk Grill (VDG)) were studied by numerical simulation. Numerical simulation by $k-\varepsilon$ 3-D turbulent flow was separately conducted to study the influence of supply velocity on the microenvironment of these two desktop task conditioning systems. Three task conditioning velocities were studied. Temperature and velocity distribution, Draught Rating (DR) and Predicted Percentage of Dissatisfied (PPD) of the room and workstation were applied to study the performance of task air conditioning. Results show that the performances of HDG and VDG are almost the same. Results also show that task conditioning can provide excellent working environment when supply velocity is well designed. The supply velocity of task conditioning can be set between 0.8-1.0 m/s. However, task conditioning may cause draught, and engineers should seriously consider this problem. The results can provide important references for design and optimization of the task conditioning system.

Key words: task air conditioning; numerical simulation; airflow; HDG; VDG; microenvironment

1. INTRODUCTION

Total-volume ventilation and air conditioning of rooms are most used at present. Rooms are used by occupants with different physiological and psychological response, clothing, activity, individual preference to the air temperature and movement. Thus, total-volume ventilation has limitations and is often unable to provide each occupant simultaneously with high level of thermal comfort and air quality. Task conditioning aims to provide clean air to breathing zone of occupants. Occupants can control the speed and direction, and in some cases they can also control supply temperature of task conditioning. Therefore each occupant can control his/her ambient environment according to his/her preference. For air supplying to workplace and individual thermal comfort control system can apparently improve microenvironment of workplace, we can properly raise background temperature and then greatly reduce indoor cooling load. Researches indicated that if we controlled the air speed around the upper half of human body by 1 m/s or higher, it was possible to raise background temperature by 31℃ or 29℃. If we enhanced designing indoor air temperature from 24℃ to 30℃, total cool load can be reduced by 35%-50% at the most[1]. Thus Cooling energy savings can be obtained notably by task conditioning.

The primary types of task conditioning system at this time can be categorized as floor-based, desktop-based, and partition-based. In our research, in order to understand air supply performance of task conditioning, we adopted CFD technology to study airflow distribution and microenvironment evaluation of workplace. We investigated the desktop task conditioning with Horizontal Desk Grill (HDG) and Vertical Desk Grill (VDG) introduced by Melikov[2] and studied the effects of supply velocities of task conditioning in the space. By CFD, we numerically

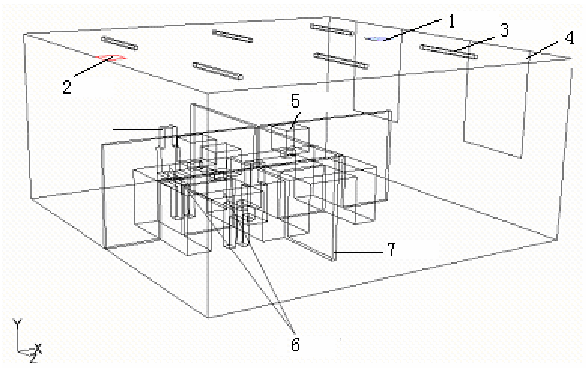
[1]Supported by the Key Laboratory of Condition Monitoring and Control for Power Plant Equipment of MOE (North China Electric Power University).

simulated the temperature and velocity distribution of indoor air and then evaluated the microenvironment of workplace typically around occupants. Finally, we make a comparison between HDG and VDG to summarize their likeness.

2. NUMERICAL SIMULATION

2.1 Physic Model

We selected a typical office with a 5.5 m by 5.5 m floor and 2.5 m high ceiling, which was studied by Faulkner. Faulkner *et.al*[3] investigated two task conditioning systems with air supply from desk-mounted air outlets and studied air change effectiveness and pollutant removal efficiencies in the room. The office contained sources of heat and air motion, including: overhead lights, three personal computers and two seated officers. Two HDG or VDG (supply outlet size is 0.4 × 0.1m) task conditioning systems were operated while a conventional HVAC system supplied air through a diffuser located in the ceiling. Air was exhausted through a ducted ceiling-level grill. Fig.1 and Fig.2 illustrate the view of the office.



1 Supply outlet 2 Return air 3 Light 4 Window

5 Computer Monitor 6 HDG 7 Partition

Fig. 1 Arrangement of office (HDG)

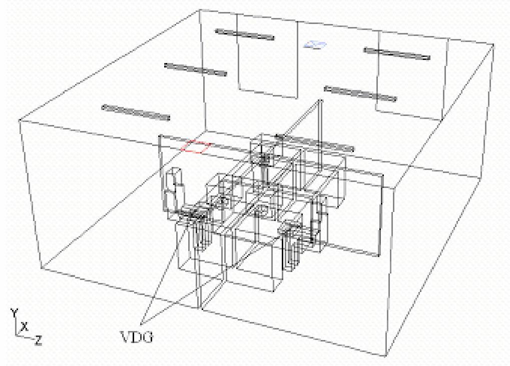


Fig. 2 Arrangement of office (VDG)

2.2 Mathematical Model

Turbulence model we most use are laminar model, one equation model and two equation model. At present, k-ε model is mostly adopted in indoor airflow[4]. Researches[5-6] obtained reliable results from applying k-ε model in numerical simulation of three dimensional airflow field of air conditioning room.

We selected k-ε two equation model as our turbulence model. The general form can be demonstrated by Eq.(1).

$$\frac{\partial(\rho\phi)}{\partial t}+div\left(\rho\bar{V}\phi\right)=div\left(\Gamma grad\,\phi\right)+S \qquad (1)$$

In order to simplify the matter, we supposed that[7]:

(1)Indoor air is impressible and can be applied in Boussinesq assumption, which considers that the change of flow density only influences buoyancy;

(2)Indoor air flow is steady turbulence;

(3)Flow field has a characteristic of high Reynolds number, and viscosity of turbulence is isotropy;

(4)Airflow velocity is slow, and dissipation heat caused by viscous force can be ignored;

(5)The affect of air leak is ignored, and air impermeability is high enough. When air conditioning is working, doors and windows are entirely closed.

2.3 Boundary Conditions

In our research, we set task conditioning temperature at 291 K, and selected three task conditioning velocities 0.8, 1.0, and 1.2 m/s to study the performance of HDG and VDG task conditioning by numerical simulation.

Room ceiling, inner wall and floor were considered as thermal insulation boundary for heat insulation ability of building materials is good. As human body is complex, we simplified it into four cuboids and took its heat extraction into account. Ceiling, inner wall, floor, computer and furniture were considered to be non-slip. Outdoor wall was regarded as convection boundary. Cooling load of office contained lights (40W × 6) and computer monitor (70W×3). Thermal boundary conditions are listed in Table 1.

Tab. 1 Thermal boundary conditions

Boundary	Boundary condition	Boundary	Boundary condition
Overhead lights	Heat flux(268.24 W/m^2)	Human	Temperature
Computer monitor	Heat flux(97.2 W/m^2)	Return air	Pressure outlet
Window	Heat flux(54.08 W/m^2)	Other Wall	Thermal insulation
Outdoor wall	Convection		

We used partial definition method[8] to define the boundary condition of air supply outlets of conventional HVAC system. Partial definition method simply divides outlet surface into some different partial air supply outlets and then defines boundary condition individually. For square diffuser, it can be illustrated in Fig.3. Consume that air velocity in the larynx is *v*, then the horizontal velocity $v_1 = v \times \sin\alpha$ and the vertical velocity $v_2 = v \times \cos\alpha$, thus we can define the boundary conditions of A, B, C and D individually.

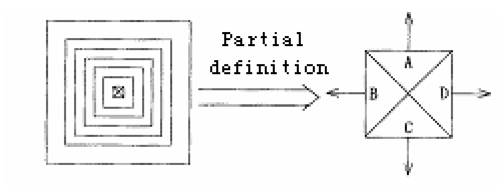


Fig. 3 Partial definition method for diffuser

In our research, air velocity in larynx was 0.264 m/s, and α is 30°. Return air was defined as pressure outlet. Standard wall function was applied in near-wall treatment.

For actual process of heat transfer is combination of forceful and natural heat convection, gravity was considered in our research.

In numerical schemes, we selected following discretization method:

(1) Pressure: Second order; Pressure-velocity couple: SIMPLE;

(2) Momentum, turbulence Kinetic energy, turbulence dissipation rate and energy: First order upwind.

(3) Convergence criterion: each residual of flow item is smaller than 10^{-3}, and residual of energy is smaller than 10^{-6}.

3. MICROENVIRONMENT EVALUATION OF TASK CONDITIONING

The microenvironment formed by task conditioning in workplace immediately influences thermal comfort and productivity of occupants, therefore, except for using velocity and temperature index, we used the other two thermal comfort indexes DR and PPD to evaluate the microenvironment in workplace.

3.1 Draught

Draught is defined as unwanted cooling of the body by air movement. The draught rating[9] in the ISO standard is:

$$DR = (34 - t_a)(\bar{v} - 0.05)^{0.62}(0.37 \times \bar{v} \times T_u + 3.14) \tag{2}$$

Where T_u is turbulence intensity,%; t_a is airflow temperature, ℃; $\bar{v}$ is mean airflow velocity, m/s.

When $\bar{v} < 0.05$m/s, we set $\bar{v}$ =0.05, and when DR＞100%, we consider DR=100%.

3.2 Predicted Percentage of Dissatisfied

We used PPD (Predicted Percentage of Dissatisfied) index to describe the dissatisfied percentage of occupants in the office. The standard ISO7730 recommend that PPD can be smaller than 10%. It means that 10% of occupants feel dissatisfied is allowed.

Fanger and Vchristense indicate that thermal comfort is determined by air velocity, temperature and airflow character. PPD in turbulence can be given by Eq.(3).

$$PPD = 1380\left(\frac{\bar{v}-0.04}{t_a-13.7}+0.0293\right)^2-0.000857 \tag{3}$$

4. ANALYSIS AND DISCUSSION

From simulation results, we can see that supplying performance of HDG and VDG are almost the same. Therefore we select HDG task conditioning to illustrate task air conditioning performance influenced by supply velocity. For the limitation of paper length, we only illustrate some of the results. And then we make comparison between HDG and VDG to summarize their likeness.

For analysis, we selected two typical section A (normal to surface X-Y, and cross through human) and B (horizontal height is 1.15 m) to study the performance of task conditioning.

4.1 Task Air Conditioning Performance Influenced By Supply Velocity

We select results of HDG task conditioning to study the performance influenced by supply velocity.

4.1.1 Temperature distribution

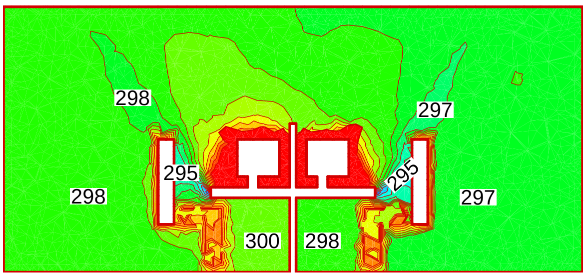


Fig. 4 Temperature distribution in section A (v=0.8m/s)

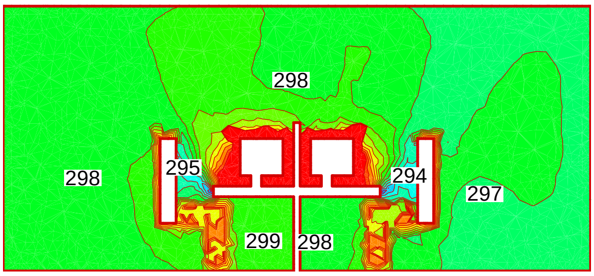


Fig. 5 Temperature distribution in section A (v=1.0m/s)

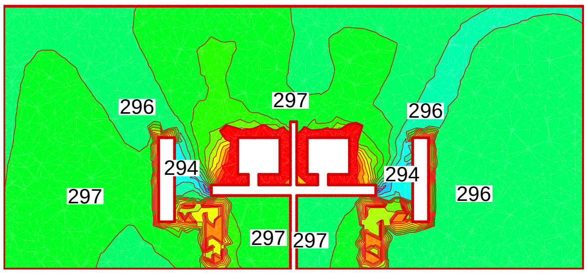


Fig. 6 Temperature distribution in section A (v=1.2m/s)

Temperature distribution is shown in Fig. 4, 5 and 6. When fresh air is sent upwards at a certain angle (45°), a low temperature area is formed in front of upper half body of occupant. In the same supply outlet size, as velocity of task conditioning increases, supply air volume increases and temperature of breathing zone reduces, so does the temperature around occupants. When supply velocity is 0.8-1.0 m/s, temperature of breathing zone and background temperature cooperate well and reasonably and it is benefit for make full use of task air.

4.1.2 Velocity distribution

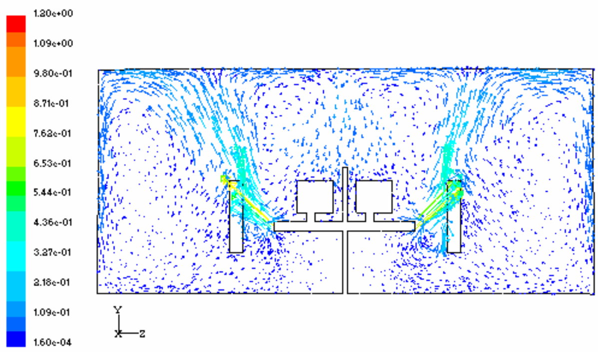


Fig. 7 Airflow distribution in section A (v=0.8m/s)

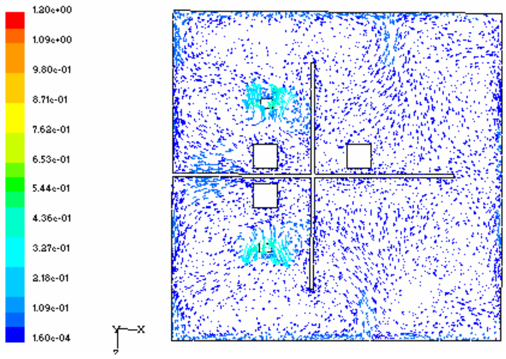


Fig. 8 Airflow distribution in section B (v=0.8m/s)

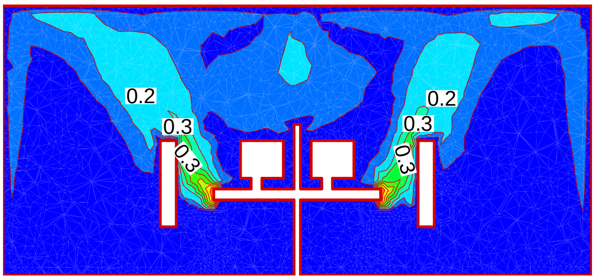


Fig. 9 Velocity distribution in section A (v=0.8m/s)

Airflow distribution is shown in Fig. 7 and Fig. 8. Fresh air is sent upwards from grill under desktop. The upper half of human body is just in task air supplying region. From Fig.7, task air forms a visible cincture around human body and separates occupant from background airflow efficiently. Thus the cincture reduces mixture between task air and background airflow and also weakens heat exchange between task air and background area at the same time. Such airflow pattern is easy to supply fresh air directly to breathing zone and also avoid fresh air contaminated by volatiles of human body and room furniture and equipment.

Velocity distribution in section A (v=0.8 m/s) is shown in Fig. 9. The other two velocity distributions are not listed. When fresh air is supplied, its velocity decays rapidly. When task air supplying velocity is low, the attenuation of velocity is slow and the gradient of velocity is small. For task conditioning sends fresh air directly to breathing zone and occupants are close to air outlets, we should pay attention to airflow velocity in workplace, breathing zone and upper half of human body to avoid causing draught. When task air velocity is 0.8 m/s, airflow velocity in breathing zone and around the head is 0.3 m/s, which meets the requirement of thermal comfort. When velocity is 1.0 m/s, airflow velocity in breathing zone is 0.4 m/s, and when velocity raise to 1.2 m/s, airflow velocity in breathing zone achieves 0.6 m/s, which greatly exceeds the requirement of thermal comfort. Therefore, large supplying velocity should be avoided, and in our cases, 0.8-1.0 m/s are appropriate.

4.1.3 DR distribution

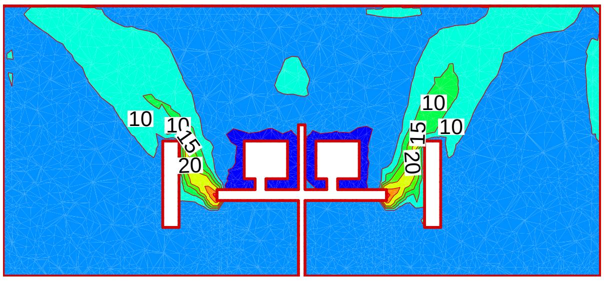


Fig. 10 DR distribution in section A (v=1.0m/s)

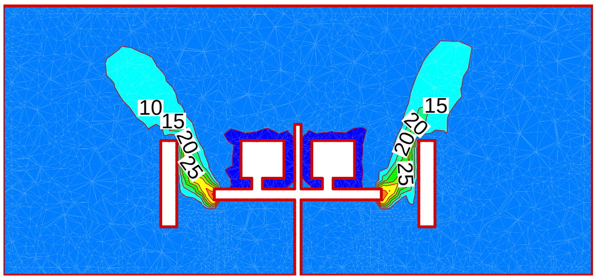


Fig. 11 DR distribution in section A (v=1.2m/s)

Fig. 10 and 11 show DR distribution in Section A. As the increasing of task air supply velocity, DR around occupants increases. Corresponding to airflow velocity, when supplying velocity is 0.8 m/s, DR in breathing zone is 15% while DR above head and at the front of head is 10%, which satisfies the demand of thermal comfort. And when supply velocity is 1.0 m/s, DR in breathing zone reaches 20%. But when supply velocity increase by 1.2 m/s, DR around occupant reaches 25%, and it will cause draught to occupants.

4.1.4 PPD distribution

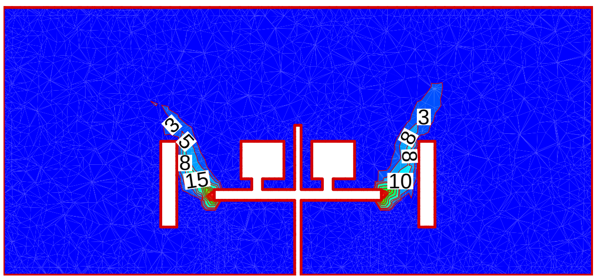


Fig. 12 PPD distribution in section A (v=1.0m/s)

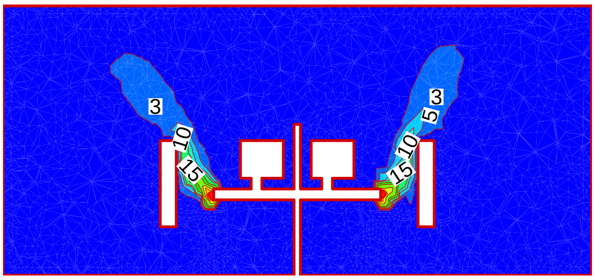


Fig. 13 PPD distribution in section A (v=1.2m/s)

Fig. 12 and 13 show PPD distribution in Section A. For task conditioning, supplying velocity of task air directly affects thermal comfort of occupants. So we survey dissatisfied degree towards task conditioning system according to Eq.(3). PPD reflects occupants' dissatisfied degree to indoor environment. When velocity is 0.8 m/s, PPD around upper half of body and in breathing zone and around head is 3-5%. When velocity is 1.0 m/s, PPD around occupant is about 8%. For the above two cases, occupants' satisfied degree is large. As the increasing of air supply velocity, draught strengthens. And when supplying velocity is 1.2 m/s, PPD around upper half of human body and in breathing zone reaches 10-15%, occupants' dissatisfied degree increases because of great draught

Tab. 2 Temperature distribution comparison

Temperature（K）	HDG			VDG		
	0.8	1.0	1.2	0.8	1.0	1.2
Breathing zone	295	294-295	294	295	294-295	294
Bacground	298-299	298	297	298-299	298-299	298

Tab. 3 Velocity distribution comparison

Velocity（m/s）		Upper half body	Breathing zone	At the front of head	Above head
HDG	0.8	0.3	0.3	0.3	0.2
	1.0	0.4	0.4	0.3	0.2
	1.2	0.5	0.5	0.4	0.2
VDG	0.8	0.3	0.3	0.2	0.2
	1.0	0.4	0.4	0.3	0.2
	1.2	0.6	0.6	0.3	0.1

Tab. 4 DR distribution comparison

DR（%）		Upper half body	Breathing zone	At the front of head	Above head
HDG	0.8	20	15	15	10
	1.0	20	20	15	10
	1.2	25	25	20	10
VDG	0.8	15	15	15	10
	1.0	20	20	15	10
	1.2	25	25	20	15

Tab. 5 PPD distribution comparison

PPD（%）		Upper half body	Breathing zone	At the front of head	Above head
HDG	0.8	8	8	3	3
	1.0	10	10	8	3
	1.2	12	12	8	3
VDG	0.8	5	5	3	3
	1.0	8	8	5	3
	1.2	15	10	10	3

4.2 Comparison between HDG and VDG

Tables 2, 3, 4 and 5 show the comparison results of HDG and VDG task air conditioning in different task air supplying velocities.

We can see that, in the same supply outlet size, supplying performances of VDG are like those of HDG. They have the similar airflow pattern, temperature and velocity distribution and workplace environment. Therefore, performance obtained by vertical supply outlet and horizontal supply outlet is uniform, and the dispose styles won't influence the task air supplying performance. The choice between HDG and VDG can be considered according to users' using habit and cooperation between supply outlet and desk.

5. CONCLUSION

The airflow distribution and microenvironment evaluation have been studied by numerical simulation in a typical office with HDG and VDG task conditioning. Temperature and velocity distribution, DR and PPD are calculated.

For task conditioning directly supply fresh air to breathing zone, we should pay attention to air velocity in workplace, breathing zone and upper half of human body to avoid causing draught. For HDG, when supply velocity of task conditioning is 0.8 m/s, airflow velocity, DR and PPD in breathing zone is 0.3m/s, 15% and 8%, and when supply velocity is 1.2 m/s, airflow velocity, DR and PPD in breathing zone reach 0.5m/s, 25% and 12%. Thus, supply velocity of task conditioning can be set between 0.8-1.0 m/s.

VDG and HDG task conditioning have the similar airflow pattern, temperature and velocity distribution and workplace environment.

The results can be used in designing and optimization of HDG and VDG task conditioning system and other task conditioning system.

ACKNOWLEDGEMENTS

This study was supported by the Key Laboratory of Condition Monitoring and Control for Power Plant Equipment of MOE (North China Electric Power University).

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